

ENTERPRISE VERSUS BUREAUCRACY

A need was established early in world war II in Britain for an indoor bomb shelter. A study made two years earlier, in 1938, defined the problems and listed the objections to placing a shelter within a house. Armed with this information, Lord Baker began the design of what was to be the successful "Morrison" bomb shelter. In this case history, Lord Baker describes the steps in his design, and tells of his problems in gaining acceptance of his ideas, his difficulties with materials shortages and substitutions, and fabrication assembly.

INTRODUCTION

Lord Baker, author of Enterprise versus Bureaucracy, from which this case history was extracted, was a member of the Civil Defense Research Committee and a full time Scientific Adviser to the Ministry of Home Security in Britain from the early days of World War II (the "phoney-war period") through August 1943 when he accepted the Professorship of Mechanical Sciences at Cambridge University.

As an Adviser, Lord Baker's charge was to carry out the necessary research and experiment in order to advise on the design of bomb shelters. When it became obvious that the shelters in use were not effective, John Baker drew upon his experience in investigating the behavior and design of steel framed buildings, and designed what was later called the "Morrison" shelter.

Of his book, which relates the events leading to the design of this successful indoor bomb shelter, Lord Baker wrote:

". . . I set out to write an account of the steps taken in design, simple enough for the layman to appreciate something of the thrill and satisfaction of an engineer's work. As the story unfolded another theme was uncovered. This was the struggle that the technical man, armed with new knowledge, almost inevitably has with authority, saddled with many responsibilities such as drafting and applying regulations or making a profit. This is a struggle which may well increase in step with the rate of technological change. The account of it may, therefore, be even more important than the straightforward design story.

"I hope that because it reveals a struggle, no reader will feel that this is a complaining book. In its modest way I consider it to be a success story. It not only tells the layman what engineering is about but shows the young engineer that some of his brightest ideas will meet opposition. He must persist. If he is working on sound principles his efforts should be crowned with success and he will find the struggle exhilarating."

THE INDOOR SHELTER

Quite early in the "phoney-war" period, attention was given to providing shelter in the home. The most effective proposal came from D. C. Burn (an engineering colleague). It was a propping system for use in a ground floor room of a dwelling house, a stout frame made of timber, with four posts, one in each corner of the room, supporting four beams just below the ceiling, to which the posts were braced by diagonal members, all being bolted rigidly together. The idea was based on an intelligent anticipation of what enemy bombing was to prove later, that the bedroom floor of the typical villa was, in itself, a strong element quite capable of supporting the debris from the roof, chimney stack and upper walls if the house was shaken down by a near miss. The timber frame did nothing to protect the shelterers from collapse of the ground floor walls but it was a comforting addition, at that time, for any house that had no other shelter.

Burn, with a family of two small boys, built one for himself and as our family of two girls was suddenly increased by the arrival of three little evacuees from Eastbourne I followed suit. These evacuees had had nasty experiences of bombing before leaving home but their nervousness was allayed by the stout timber props when a "protected room" was built to house them and their small hostesses. This propping was given official blessing by being described in a Ministry Bulletin No. Cl4, in which the illustration showing the construction of a protective wall was a photograph of our installation.

Since timber, in short supply, was needed for the frame they could not be provided in great numbers but there are records of 1365 rooms being strengthened in this way, of which 218 were destroyed mostly by fire. Later in the war, however, one in Exeter was to fulfil its purpose admirably. The propping had been erected in the back room of a two-storey semi-detached house built in 1892 with 9 inch external brick walls, timber floors and a slated roof. At 23.30 hours on 23 April, 1942, a 500 kg bomb fell outside the house 27 feet from the corner of the propped room, forming a crater 10 feet deep and 30 feet in diameter. The house was completely demolished but the propping did its job. It protected the occupants, one woman and two children who were in bed under it. They were unhurt, apart from a bruise on the woman's knee.

Though the Government Anderson shelter issued to householders for erection in their gardens was structurally sound, it soon became clear that this form of shelter had been

made ineffective by the change in the enemy's tactics. The Anderson was essentially a trench shelter and though it did not suffer from the structural defects of the standard concrete linings, since it was continuous and ductile, it shared all the other drawbacks of trenches. It would have been tolerable if the conditions envisaged when it was designed had continued, that is to say if the enemy raids had been of short duration. However, when the pattern of all-night alerts was established, as happened in London in September 1940, it was obvious that the Anderson shelter would be quite unsatisfactory when winter came. Each one of us who left London at the end of a day's work, from September onwards, filled his passenger seats with worried men, anxious to get to their suburban homes so that they could see their families safely installed in their garden shelters before night fell. When the shelters were cold holes in the ground, which would always be damp and often flooded in wet weather, the prospect of the long winter nights was not encouraging. Local authorities did what they could by providing bunks so that the shelterers could go to bed but nothing effective could be done to stop the flooding or even to reduce the damp. It was soon realised that there was a factor other than structural safety essential in shelter design and that was "occupancy factor." It was impossible to claim that a shelter was efficient, however small its vulnerable area, if its occupancy factor was zero, that is to say if no one would use it. There was every prospect that the Anderson shelter would come into this class with a resultant rise in casualties and a fall in morale.

None of this had been realized at the time of Mr. Morrison's¹ visit to Princes Risborough² and so no steps were taken to provide more effective protection for the family. We in the Design and Development Section (RE4) soon realized how serious this omission was and took steps to correct it. I approached the Chief Engineer's Branch with the proposal that a shelter should be designed to accommodate a family inside its own house. I did not submit a design but merely sought recognition that this new project should be added to the heavy load of design work already in hand which, it had been stipulated by the Minister, must be carried out in agreement with the Chief Engineer. No reply was made to this proposal. I persisted firmly but politely, in true civil service

¹Herbert Morrison, Home Secretary and Minister of Home Security

²the site chosen to house the Ministry of Home Security in offices vacated by the Forest Products Research Laboratory.

fashion, addressing Minutes to the Chief Engineer. Nothing happened for some weeks, then a reply was received. Unfortunately no copy has survived but I remember the gist of it vividly. It came from Mr. Osmond, a kindly and quite senior administrative officer in "O" Division. It said that no new project was to be undertaken since it was impossible to provide safe shelter inside a house; this had been established in 1938 by a panel of eminent engineers. I was referred to Command Paper 5932.

No one in RE4 had ever heard of the Command Paper. This may be a reflection on the efficiency of the Research and Experiments Department but it is also a sure indication of how our work had been limited. The Chief Engineer was responsible for shelters and therefore for papers dealing with their design. These had not been brought to the notice of the scientific advisers, through the Civil Defence Research Committee or otherwise. On becoming heavily involved early in October in the design of shelters I should, of course, have taken immediate steps to seek out and study any literature relating to the subject. Needless to say I lost no time, after receiving Osmond's Minute, in obtaining a copy of the Command Paper.

It proved to be a document of the greatest interest, being nothing less than a Report on Air Raid Shelter Policy which had been, as the title page put it, "Presented by the Secretary of State for the Home Department to Parliament by Command of His Majesty, December, 1938." I had been amused by Osmond's use of the adjective "eminent" in his description of the panel of engineers: I had considered it merely a mild rebuke to a somewhat troublesome, pushing young man, but it was completely justified. The Report had been drawn up by David Anderson, doyen of British civil engineers, senior partner in the civil engineering firm of Mott, Hay and Anderson; B. L. Hurst, the most successful consulting structural engineer of his time, senior partner in the consulting firm B. L. Hurst and Partners; and Sir Henry Japp, KBE, a leading contractor, chief engineer and works director of the civil engineering contracting firm of John Mowlem and Co. Ltd.

Though their report deals briefly with the whole problem of the provision of shelters, it is mainly concerned, as its opening paragraph emphasizes, with the sectional shelter. The term "sectional" is not defined but it is clear from the context that it refers to the heavy corrugated sheet steel arched sections which made up the trench lining, illustrated in Fig. 1, which was later issued to householders and popularly called the Anderson shelter, named not after David Anderson, the engineer whom the public would

not know, but after Sir John Anderson, the Lord Privy Seal and later the first Minister of Home Security, to whom the Report was addressed.

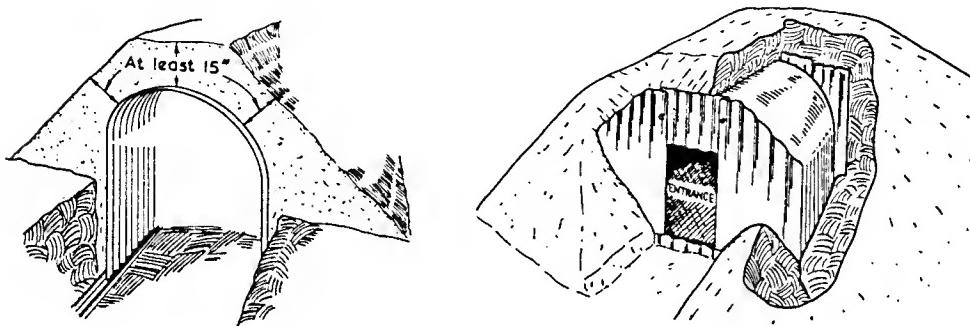


Fig. 1

The report was of such value to the Design and Development Section that that part dealing with the sectional shelter must be reproduced in full.

Report to the Lord Privy Seal

"We have had the opportunity of discussing with the Lord Privy Seal some of the problems of the shelter policy, and in particular the proposal to provide sectional shelters for the population of vulnerable areas in their own homes.

In the first place we would record our whole-hearted agreement with the Lord Privy Seal that the provision of a shelter in or in close proximity to the home of every citizen in vulnerable areas is a sound policy, and that such shelter should provide reasonable protection against blast and splinters from the near-by explosion of a medium-sized H.E. bomb and against the collapse of the super-structure, and we have now to record our opinion as to how far a sectional steel shelter can fulfil the requirements of this policy.

I (a) A sectional steel device is one method of providing such shelter. There are a number of such devices on the market and we consider that two or three standard types could be adopted which would satisfy the requirements and

which would enable a large number of firms to adapt their plant to the production of one or other of the types with the least possible delay.

(b) Such a shelter should measure not less than 6 feet by 4 feet 6 inches in plan and should not be less than 6 feet high from the crown of the arch to the floor. This shelter would hold four persons for a short period and might even in an emergency hold six persons. It would, therefore, form the minimum shelter for the two-storeyed terraced house or cottage type of modern house, which on the average, accommodates rather under four persons. The dimensions given are in our opinion the absolute minimum for three reasons:

(i) Anything smaller would have no market value above its value as scrap, whereas a structure of the minimum size which we recommend would have a definite value for other useful purposes.

(ii) That there would be serious risk of very rapid suffocation in any smaller shelter in the event of the exits being blocked, and

(iii) Anything smaller would be unacceptable to the people and we would particularly emphasize the danger of issuing a type of shelter which could only be entered by crawling and in which only a crouching or recumbent attitude is possible.

(c) The weight of such a shelter would be from 5 cwt to 7 cwt.

II With regard to the position to be occupied by these shelters we are definitely opposed to the placing of them within houses for the following reasons:

(a) The ordinary ground floor room of the small house measures only about 10 feet by 12 feet and therefore such a room would be to all intents and purposes out of action whilst the shelter was in it. Every air raid will reduce the available accommodation and increase the pressure on undamaged houses in already overcrowded areas, and it is therefore an error to render any accommodation useless for normal purposes.

(b) The shelter would provide no additional protection against splinters beyond that which the walls of the room provide, and would have no resistance to splinters entering through the doors or windows.

(c) Unless the floor of the room were removed and the shelter placed on the ground below (generally about 15 inches below the floor), there is danger of the shelter being driven through the floor by the collapse of the house, to the added danger of the occupants.

(d) Unless the shelter were strongly anchored to the floor, the collapse of one side of the house would incur the risk of its displacement and distortion.

(e) There is a very serious risk of debris from the fall of the house forming a solid wedge of masonry at the ends of the shelter making the rescue of the occupants very difficult. For the same reason there is a risk of the occupants being suffocated from lack of air and by the dust from the debris. The higher the house the greater will be this risk.

(f) Assuming, as seems most likely, that an attack with H.E. bombs will be accompanied by the use of incendiary bombs, the risk that the shelter will become an oven for the trapped occupants is a very real one and one which we consider would render the acceptance by the people of the device for use inside a house more than doubtful.

(g) There is a risk that the entrapped occupants may be killed by the escape of gas from the domestic supply (the gas mask is not proof against this form of gas).

A shelter device of this kind, to be provided in large numbers, must in our judgement satisfy public opinion. Undoubtedly most people would prefer to stay in their houses to take shelter, and though at first sight the device might seem to render this possible, the plain truth is that if they do so, within the protection of such a shelter, their chances of rescue are greatly diminished and the prospect of a lingering death increased if the house collapses. Ease of exit is the most fundamental requirement of a proper shelter and ease of exit from a sectional shelter within a small collapsed house is almost a contradiction in terms.

There is, however, in our judgement, a very definite place in the shelter policy for a steel shelter device of this kind for small houses. During the recent crisis the Home Office recommendation that the householder should dig a trench in the back-yard or garden was severely criticised on the grounds that many could not afford the cost of the materials necessary to revet the trench, and there was a demand for the free issue of material for the purpose.

The sectional device is an answer to this criticism. Placed

in the garden or yard and covered with earth or sandbags, it provides as good a shelter as a covered trench. It should be sunk at least partially in the ground as this not only provides increased lateral protection but also provides the earth necessary to cover the shelter. Thus protected it can be placed close to the house without serious risk from the collapse of the building."

* * *

This report was of such interest and value, not so much because it came down so firmly against placing the shelters within houses, but because the reasons for this decision were set down in Section II.

The first step in design is to define the problem, to state clearly the aim and object of the exercise, then to list any constraints and other difficulties that must be overcome. The eminent authors had defined the problem completely and set out the difficulties and objections clearly in the seven paragraphs of Section II and the comments that followed. All that the designer in 1940 had to do was to consider these seven objections and to find ways of overcoming them. He had two powerful advantages over the panel working in 1938. He had the evidence of the full scale experiments being provided daily by the enemy and he was not constrained by the elastic theory of structures.³ I was confident that with these advantages we could design an efficient open frame structure and so reverse the panel's decision. Mr. Osmond was so informed but he did not relent. Then on 1st December, 1940, the Chief Engineer of the Ministry of Home Security telephoned from Whitehall and a conversation something like this took place:

"Baker, we'll have to do something about an indoor shelter. The Prime Minister is on our track. Will you come up and help me choose one?"

"What do you mean, choose one?"

"Oh, we've got dozens of designs here. Every Tom, Dick and Harry in the country has suggested something."

"I certainly won't come and choose one; give me a day or two and I'll bring up the plans of a shelter which has really been designed to behave properly."

³Editor's note: About 1935 Professor Baker had investigated the collapse loads of steel structures and developed design methods like limit design which allow for local plastic deformation. See The Steel Skeleton, Vol II, Cambridge University Press, 1956.

The gist of this conversation stayed clearly in my mind because Chief Engineer Rouse's request seemed so odd. Though socially we remained on good terms our professional relationship had been under some strain since October while the standard shelters were being redesigned by RE4, an activity which could be considered a criticism of the Chief Engineer's earlier work and of his authority. Yet here he was appealing to me, who claimed to possess the secret of efficient design and who had been pressing for months for the opportunity to produce an indoor shelter, to come and help choose some amateur's effort.

It is certainly the last thing I would have done in similar circumstances. Nevertheless I went up to London a few days later with a sketch design of an open frame structure and showed it to Rouse, an administrative officer of "O" Division named Hutson and others. The design was not received with any enthusiasm for the simple reason that a shelter had already been selected and a mock-up was already standing in the corridor outside. It was a steel shelter, in cross-section the shape of a Gothic arch, with ribs of bent rolled steel section covered with quarter inch thick steel plate and with steel plate flaps closing the ends. It obviously did not satisfy any of the specifications for an indoor shelter. It was, in effect, a sectional shelter which the Command Paper had rightly described as a death trap. Quite apart from this, it was of such complexity that it could not have been mass produced easily and cheaply, as a Government issue shelter would have to be to meet the emergency then facing the country.

I pointed out all these shortcomings quite forcibly but to no purpose. I was baffled. To jump to it and reconsider the problem of the indoor shelter when instructed by Prime Minister Churchill, whatever difficulties were involved, was proper enough, but to produce a solution which ran absolutely counter to the advice of that panel of eminent engineers, which up to that moment had been used to block all action, passed belief.

As soon as our meeting broke up, Rouse's personal assistant told me what had happened. Apparently, Mr. Churchill, a few days before, concerned as he would be at the hardships of the common people and the possible danger to the war effort of any serious drop in their morale, had said to Mr. Morrison, "Herbert, you must give the people a shelter in their own homes," then not for the last time, he had gone too far with his instructions and said "Something like this," taking an envelope from his pocket and drawing on it an inverted U shape. This was immediately and indelibly

printed on the bureaucratic mind so, from the amateur designs available, one as close as possible in outline to the Prime Minister's arch diagram had been chosen. My sketch design had a flat top, so it was automatically ruled out. However, I knew that the Gothic arch shelter would be a fiasco and must be stopped, so I returned to Princes Risborough to complete our design. The steps involved are easily retraced.

If the extracts from the Command Paper are studied, it will be seen that the main objection to placing a sectional shelter inside a house was the fear that the occupants might be trapped by the debris when the house collapsed. This is stressed in paragraphs II (e), (f), (g) and in the following paragraph which ends with the sentence "Ease of exit is the most fundamental requirement of a proper shelter and ease of exit from a sectional shelter within a small collapsed house is almost a contradiction in terms." Anything like a sectional shelter with only one exit was therefore out of the question. Debris might flow on to a shelter from any direction so, to give the shelterers the best possible chance of escape, exits must be provided on all four sides.

This postulated an open frame structure, something like the frame for a single-storey steel framed building or the portals tested at Bristol.⁴ Why had the authors of the Command Paper not considered this form? They could only work within the limitations of their time and so were confined to a consideration of elastic behaviour. Had they thought in terms of absorbing the energy of the collapsing house they must have considered the open frame solution impracticable. The potential energy of a typical two-storey villa, or cottage type of modern house as the panel archaeologically described it, is equivalent to about 150 tons falling 10 feet. To absorb this energy which is released by the falling house, without exceeding the yield stress of the steel, would have required so heavy a frame that, quite apart from the expense, it could not have been carried into the villa. The authors had, unfortunately, no experiments to suggest to them that a smaller value for the energy might be justified or that a frame could be made to absorb it safely.

Our next step was to decide the overall dimensions of the shelter. The key to this lay in paragraph II (a) which warned that space would be at a premium once raiding began. The obvious reply was to make the shelter a useful article of furniture so that it would not put the room out of action, and even to go further and make it dual purpose so that it

⁴See The Steel Skeleton, Vol II.

would actually economise in space. This was done by making it a bed by night and a table by day. The usual size of a double bed is 6 feet 6 inches by 4 feet 6 inches and the height of a dining table is 2 feet 6 inches and so the dimensions were fixed. This is a great moment in an engineer's day when he can draw lines on his paper defining the shape and overall dimensions of his structure. However, it does not settle for him the sizes of the members which will make up his structure. For this, an estimate of the energy to be absorbed is first required. Here the 1940 designer had the great advantage that, even by the end of that year, he could draw on an immense amount of experimental evidence. The German bombs that, as near misses, had shaken down houses showed that one part was surprisingly strong; that was the bedroom floor, consisting of timber joists to which the floor-boards were securely nailed. It almost always fell in one piece, either more or less horizontally if all the walls collapsed together or, more usually, hinged to the wall edge when only the walls nearest the bomb went. This latter was the most rigorous condition since the entire impact might be carried by only one top longitudinal member of the shelter and the blow would be inclined to the vertical, whereas a horizontal fall would be taken straight on to the vertical legs. The floor, having been brought to rest by the shelter, was in a position to protect it from the impact of further falls of roof and upper walls.

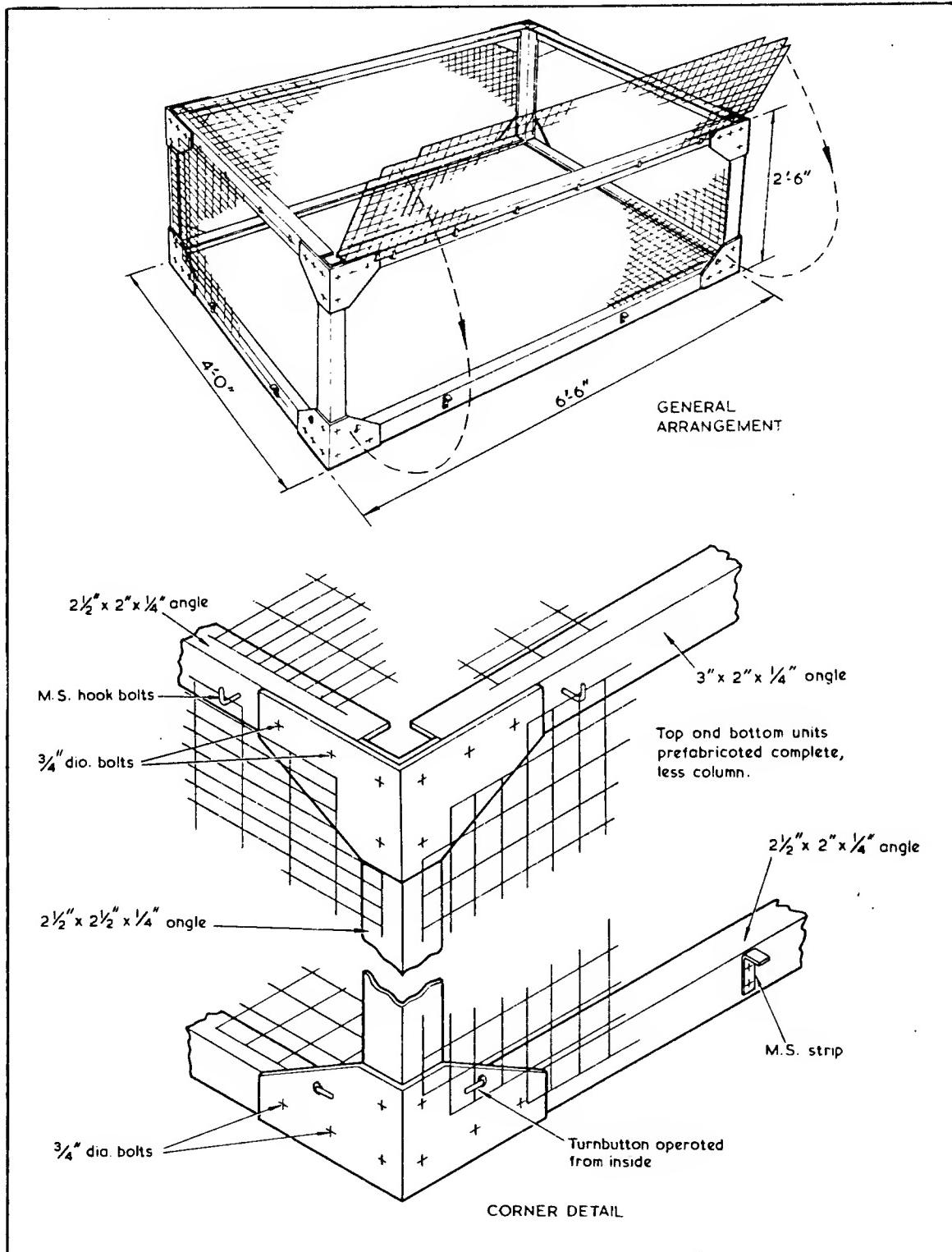
A typical room would not exceed 14 feet in span and 9 feet in height with the weight of floor and bedroom furniture 20 lb per square foot. The total energy of that part of the falling floor to strike the shelter was thus calculated to be 142,000 inch-lb. For a preliminary design, to be checked by subsequent test, it was assumed that only one half of this energy need be absorbed by the shelter, the rest going into the floor below and elsewhere. For reasons that will be obvious, it was decided to provide rigid joints between the horizontal and vertical members. For further economy the greatest possible permanent deflection had to be allowed. Since the shelter was to be 2 feet 6 inches high, it was considered that the top horizontal members could deflect at their centers by 12 inches without causing injury to even the stoutest occupant, always assuming he was lying down-- if he was not when the bomb exploded, he certainly would be by the time the house collapsed. From these dimensions and assumptions it was calculated that a structural steel member 1/4 inch thick, in the shape of an angle with one leg 3 inches long and the other 2 inches (i.e.) a 3 inch by 2 inch by 1/4 inch angle, would be more than adequate. To confirm this, a shelter was constructed and placed on a

concrete slab, which would absorb less energy than any normal ground floor. A timber joisted floor 14 feet long and 5 feet 3 inches wide weighing 20 lb per square foot was erected 9 feet above the slab and, hinging on a short edge, was allowed to fall on the shelter. The permanent deflection of the 3 inch by 2 inch horizontal member was only 6-1/4 inches instead of the 8 inches which had been estimated.

The final design of the frame is shown in Fig. 2, where it will be seen that the rigid joints were obtained by bending steel plate around the corners and attaching them to the ends of the horizontal members and to the vertical member, which was 2-1/2 inch by 2-1/2 inch by 1/4 inch angle, with two 3/4 inch diameter bolts, 2.75 inches apart.

While the steel framework alone would protect the shelterers from the falling floor it would not prevent them from being suffocated by the dust and debris that would follow the explosion. The framework had, therefore, to be clothed with some form of protective panelling. This had to be of open mesh construction first because any light sheet material, such as corrugated iron, would be blown violently into the shelter by nearby blast and secondly on hygienic grounds since four people were likely to occupy the shelter for hours at a stretch. A great hunt, conducted by D. C. Burn, revealed no suitable fibre or fabric netting but it did confirm that steel "weld mesh," made of high tensile wire arranged in a rectangular mesh welded at every intersection, a material commonly used as reinforcement for concrete roads, was ideal. It was rigid enough to be handled as a panel, requiring no frame, and it was immensely strong. It was decided that nothing else would do and that a fight would be made for a sufficient quantity, not only for the side panels but also for the bottom, acting as a mattress, and for the top. This top might not appear strong enough but, when bolted around all four edges to the top angles of the shelter, tests showed that it would hold up any block of brick-work that might be blown on to the shelter. It was, in fact, in common with the side panels and bottom, strong enough in impact to develop the full strength of the main angle members to which it was attached and there was no point therefore in looking for something stronger. It remained, of course, for the householder to show some initiative and provide plywood or linoleum as a covering when he wished to use the shelter as a table.

The side panels were loosely hung on steel hooks screwed into the top angle, the lower line of wire just passing under a steel (MS) strip angle screwed to the bottom member and shown in Fig. 2. When the debris was thrown against the panel, it



Morrison Shelter - Preliminary Design

Fig. 2

bent inwards. This brought the top and bottom wires hard up against the hooks at the top and the steel strip angles at the bottom, so that the vertical wires of the mesh were thrown into tension and successfully kept all debris out. As the shelterers tucked themselves up for the night, they operated from inside the shelter a turn button, shown in Fig. 2. This kept the panels tight up against the framework ready to receive debris. It had the additional advantage that it prevented anyone falling out of bed if the shelter was crowded, or, to be less flippant, if the shelter was moved violently by an explosion. A turn of the button in the morning released the panel which swung up about the top row of hooks allowing exit from all four sides. When the shelter was to be used as a table the panels were merely lifted off the top hooks and stored elsewhere. If in a severe bomb incident, the shelter was completely surrounded by debris, it would be relatively easy for the rescue squad, equipped with wire cutters, to make the necessary escape hole in the mesh panels.

It is interesting at this point to turn back to the Command Paper to see how far the design meets the seven objections set out there. It does so in the following way:

(a) The shelter has a secondary use as a table, what is more, being open-framed it does not cut down light to any part of the room.

(b) War-time experience had already shown that the walls of the normal house were sufficient protection against splinters. The shelter had to be so positioned that a bomb fragment would have to penetrate at least one wall. For example, it should not be placed in front of a French window. The height of the shelter prevented the occupants from rising above window sill level.

(c) The design incorporates a firmly attached bottom independent of the floor of the room. There would be no danger to the occupants, or to the shelter, if it were driven through the floor.

(d) There is little risk to the occupant from displacement; care had been taken to avoid large flat vertical surfaces for blast to act on. The basic principle underlying the design of the structure was to allow large distortion.

(e), (f) and (g) refer to the danger of trapping. The danger of this had been minimized by supplying easy exit in every direction. If the occupants could not escape immediately, they ran no danger of suffocation since the side

panels prevented debris covering them. Dust certainly would be present but war-time experience had already shown that if anyone trapped had their hands free and so could cover their faces, as they instinctively did, this was sufficient to prevent injury from dust. The risk from fire was not serious; the dust and debris thrown up were most effective in putting out fires. Escaping gas from the domestic supply might certainly be a danger and could only be minimized by providing all possible escape routes.

The Design and Development Section worked extremely hard with their search for materials and their preliminary tests, so that the final design of the shelter was ready in not much longer time than has been taken in writing down the account of its progress. This was fortunate because I, who was not without friends in the Chief Engineer's Department in Whitehall, was warned that the prototype arch shelter, a mock-up of which had been on view early in December, was to be taken to Downing Street (the Prime Minister's residence) at 12 noon on 31st December, to be inspected by the Prime Minister. I felt that argument, however firmly it was backed by theory and design, was no match for this direct action. The only way to counter it was to produce a better article for the layman to see and touch. I therefore decided to build a table shelter and to get it into Downing Street somehow.

The Forest Products Research Laboratory workshops were enthusiastic with their help. They secured the necessary material in a remarkably short time and had a full-sized shelter built and loaded on a lorry by the early morning of 31st December. So we set off with it to London without any firm plan. We were allowed to drive into Downing Street without any questions being asked. There, outside No. 10, stood the dignified figure of Sir Alexander Rouse supervising in person the transport of the arch shelter into the house. I approached him. Sir Alexander said cheerfully "Hello, what are you doing here?" "I've brought the Ministry of Home Security Indoor Shelter," I replied.

Rouse looked ruefully into the lorry, paused for a horrifyingly long minute and then said, resignedly but cheerfully, "Oh well, you'd better bring it in."

So the table shelter was carried into No. 10, across the hall into a room on the left, where it joined its rival.

Walking down Whitehall back to Rouse's office in the Home Office Building, I asked when the Prime Minister was to be shown the shelters.

"At 5 o'clock," said Rouse "but there is no need for you to be there." I remonstrated pointing out that no one else knew anything about the design and that a rectangular steel box by itself was not likely to impress the Prime Minister or anyone else. But Rouse would not give way. It may very well have been outside his power to add anyone to the deputation. I did not realize this at the time and unkindly put the refusal down to baser motives, and so kept on nagging. By this time we were in his office and the request was referred to some higher authority, perhaps the Permanent Secretary, or even to the Minister himself. Eventually the instruction came down that "Professor Baker could go to Downing Street but he was on no account to speak to Mr. Churchill." This struck me as an amusing restriction but I did not quarrel with it. Just as I was leaving the office a messenger came in to say that the meeting with the Prime Minister had been postponed until 6:00 p.m.

Over lunch I had an unworthy thought. Was it possible that this message was a put-up job? Was the Headquarters team so keen on getting their arch shelter approved that they would be glad if there was no one present at 5:00 p.m. to explain the table model? Frankly, I thought they might. Diffidence prevented me taxing them with this so I decided to play the idiot child. I presented myself at the door of No. 10 soon after 4.30 p.m. A uniformed messenger opened the door. I said that I had to demonstrate one of the shelters brought in that morning but could not remember whether it was to be at 5:00 or 6:00 p.m. Could the messenger find out?

"No," said he, "but you can come in and wait," indicating an old-fashioned canopied watchman's chair. There I sat for upwards of an hour and a half (my base suspicions had been groundless) and watched enthralled while war leaders and statesmen went in and out. Eventually Mr. Herbert Morrison, Rouse and Hutson arrived. We went into the room where the shelters were.

Morrison was shown the arch type and then noticed the table shelter. There was just time to tell him about it, explaining the principles underlying the design when Mr. Churchill, accompanied by Admiral Sir Roger Keyes, Commander-in-Chief of the recently formed Combined Operations Force, entered the room.

The Prime Minister looked magnificent, fresh complexioned and buoyant, a great contrast to the last time I had seen him in the summer of 1939. That occasion was a Degree Congregation dinner at Bristol University. Mr. Churchill, as Chancellor of the University, had proposed the toast of the

chief guest, Mr. Kennedy, the United States Ambassador. Churchill made one of his great speeches, an impassioned plea for the two great English-speaking nations to go hand-in-hand down the dangerous road of the future. Kennedy had, no doubt, already written Britain off as a dead loss. At all events his reply was a conventional little speech which ignored everything Churchill had said. The comparison between the two men, as the high-table guests filed out in procession, was striking. Kennedy then was the one who looked fresh complexioned and buoyant, while Churchill was bowed and grey complexioned as if he realized that his cry had once more gone unheeded. Perhaps he knew too that many of the diners, narrow little academics that we were, disapproved of their Chancellor taking such an opportunity to make what they took to be a political speech instead of talking about "the need for poets," or some such scholarly topic, as Chancellor Stanley Baldwin had recently done at Cambridge.

After the introductions, Morrison said, indicating the arch shelter:

"There you are, Prime Minister, that's the kind of thing you wanted." Churchill went and sat on the edge of the table shelter, which he obviously thought was a piece of furniture, and looked approvingly at the poor arched object. Nothing much else occurred until Morrison said, "By the way, you are sitting on another one."

The Prime Minister got up and turned around to look at what he had been sitting on while Morrison proceeded, in a most impressive way, to recount all that he had been told about a structure that he had neither seen nor heard of until ten minutes earlier.

The Prime Minister listened and then turned to Rouse and said, "But this is not as strong as an arch, is it?"

Rouse sensibly passed the question to me. I explained what the reader already knows, that the problem was not so much one of strength as of energy absorption. This interested the Prime Minister who continued to question me and no one, of course, remembered the injunction forbidding me to speak. He was quick to appreciate all the points that had influenced the design as set out above. These rather blackened what reputation the arch, or sectional, shelter may have had and it was not looked at again. However, the merits of the table shelter were thoroughly thrashed out until Churchill, thumping the top of it vigorously so that the weld-mesh

panels rattled, said, "This is the one. Make half a million in the next three months. Give them to the people. Show them that it is safe. Blow a house up on one. Put a pig in it, put the inventor in it," poking me playfully in the ribs.

So that was that; the day was won. But the interview was not over. The party became social and for half an hour Churchill and everyone relaxed, except the poor civil servant Hutson who had been silent and spellbound throughout. The conversation kept mainly to engineering topics with a distinctly nautical flavor. It was not too serious. One of the Prime Minister's sallies was, pointing to the table shelter, "It wouldn't take much to design that; not like designing a warship." I had to admit that it had not been quite as complicated a task as designing a warship.

Just as the party was breaking up after the most memorable hour of my professional life, Morrison made a remark which might have caused endless trouble, and was not worthy of so astute a man. He must have felt that, in being deprived of his arched shape, the Prime Minister had been slighted, for he said, "I tell you what, Prime Minister, we can have two shelters. This one with a flat top and a new arched one. I am sure Baker can design one to be as satisfactory as the other. Then the housewife can have her choice."

I felt that it was no moment to argue, so I weakly acquiesced. What a prospect it would have been had a choice been available, what complications for the supply department and what confusion for the housewife who was not practiced in sizing up the relative merits of air-raid shelters. I knew that if the dangers of the sectional shelter were to be avoided, the only way of doing what had been asked would be to substitute for the flat top of the table a piece of corrugated iron bent in arch form. This seemed rather silly, but, in the weeks that followed, we did make some attempt to produce an acceptable design, then quietly forgot it. As far as is known, no official enquiry was ever made about the proposal.

The day may have been won, but unfortunately even the Prime Minister's instruction to make half a million in three months did not automatically produce the materials for the job. The first trouble was over the supply of wire. The "weld-mesh" or BRC fabric used to cover all the faces of the shelter was made of wire. Apparently all wire in war-time belonged to the Admiralty, who were not anxious to part with any. Home Security was told that no wire could be made available and considerable pressure was brought to bear on me to use some other sheet material. This pressure I resisted. Those days of working with the supply department of the

Ministry of Home Security were not pleasant ones. There was no feeling of cooperating to produce the best possible shelter. Whenever a deadlock was reached, the attitude at Headquarters was, "Well, Baker, that puts your shelter out." It would have been better if the reaction had been "that puts our shelter out." However, as every innovator must, I persevered. I was so convinced that weld-mesh was the only material for our purpose that I eventually persuaded the authorities to supply enough wire to make the side panels or screens. The further problems were then realized to be too big for Home Security's own supply department so I moved to the Ministry of Supply's Steel Control, which was situated at Ashorne Hill, a house near Leamington Spa, to argue the case.

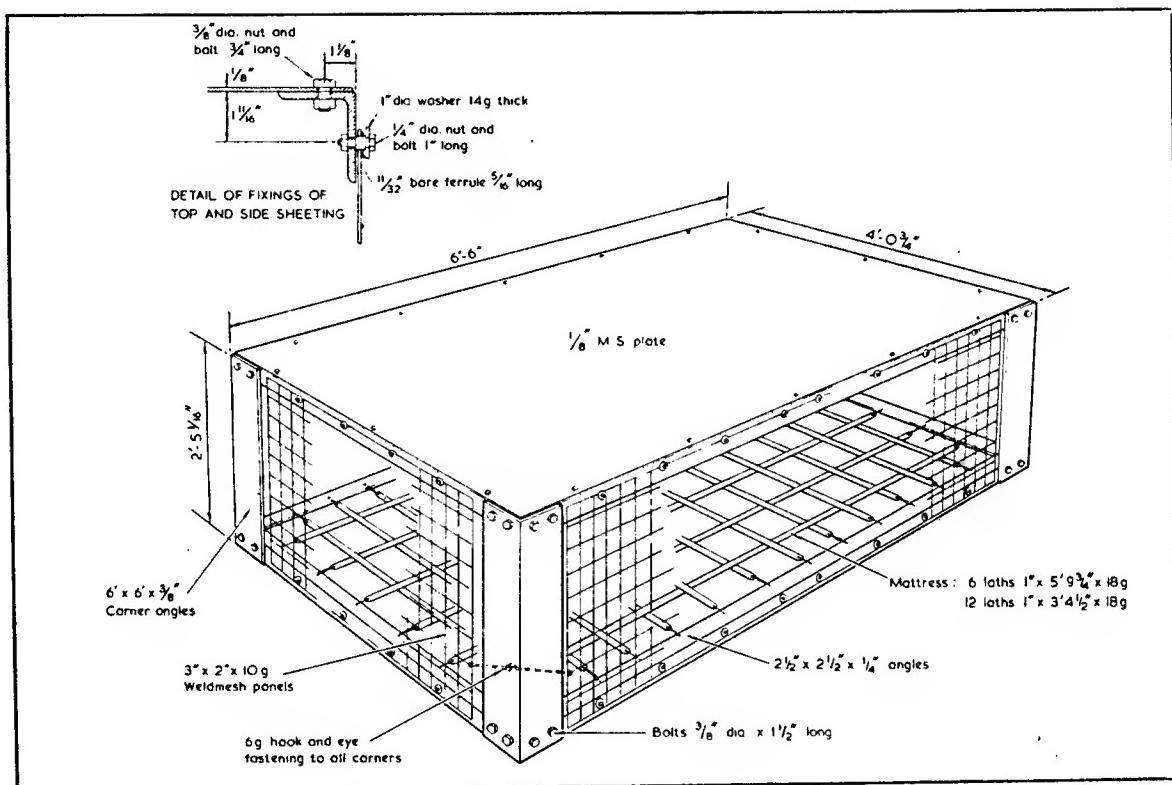
This was a more relaxed atmosphere. I was alone dealing with steel people; however, we were not out of the wood. A problem of real magnitude faced us. The shelter had been designed throughout so that it could be easily mass produced but an order for half a million needed an amount of material that was staggering. For instance, 15 million feet of one size of steel angle 2-1/2 inch by 2 inch by 1/4 inch was required. It was soon broken to me that such a quantity could not be produced in three months if all the rolling mills in the country were put to work on it alone. The same happened with nuts and bolts of which 32 million of one size, 3/4 inch diameter, were needed. The Steel Control staff, who obviously thought the whole project entertaining, were delightful. When we reached an impasse and it was decided to redesign the structure to fit the materials that were available, I was provided with an aide-de-camp. We sat together in a small room which seemed to be full of telephones connected to the Director of small angles, the Director of big angles, of nuts, bolts, strip and every other conceivable variety of steel product. These directors could say at once what quantities of their particular product would be available within the next three months and so the redesign began.

Such an exercise would have been impossible in any reasonable time if the original design had not been completely rational. It would have been extremely difficult if the design had been based on elastic behaviour. What made it possible was that being based on plastic theory it could be assumed that larger meant better, that is to say that if a member were replaced by a larger one then the collapse load of the structure would be increased.

There were some great strokes of luck, due in the main to the availability of stocks of material not in demand in

war-time. The most fruitful find was the stock of 6 inch by 6 inch by 3/8 inch angle. This large member was available for the four table legs. It was wide enough to accommodate the two bolts at the ends of the top and bottom rails. This meant not only that the eight expensive bent plate gussets could be dispensed with, but that the number of 3/4 inch diameter bolts could be halved, a saving of a cool 16 million.

Another piece of luck was the provision of solid plate for the top. Apparently some civil servant had been sent to America at the beginning of the war to secure supplies of steel for the ship-building industry. Among his purchases were acres of plate 1/8 inch thick. Unfortunately no one had told him that nothing less than one quarter inch plate was used by British shipbuilders. Something that could not have been contemplated in the original shelter design because of its extravagance was thus willingly provided. The plate made a good firm top for the dinner table and having solid steel above his head gave the shelterer more confidence. A brilliant solution to the problem of the expensive hooks from which, in the original design, the side panels were to hang, was provided by an anonymous member of Steel Control. The hooks were replaced by a row of eight 1/4 inch bolts one inch long carrying a one inch diameter washer which was kept hard up against the head of the bolt by a 5/16 inch length of 11/32 inch bore ferrule as shown in the inset to Fig. 3 which illustrates the shelter as issued to the public. The top horizontal length of wire in a side panel rested on the ferrule passing through the 1/4 inch bolt. An exactly similar row of bolts, washers and ferrules was inserted in the bottom rail of the shelter, so positioned that the bottom horizontal length of wire in the side panel just cleared the lower edge of the washer. When debris struck the panel it bent inwards and brought this bottom length of wire hard up against the ferrule on the bolt so that the full tensile strength of the vertical wires could be developed to resist the pressure of the debris. The brilliance of this simple piece of production engineering was that it enabled the side panel to be opened by hinging not only at its top edge but, alternatively, at its bottom edge. If, when in place, the panel was moved upwards in its own plane until the bottom wire came hard up against the ferrule, then when it was swung outwards from this bottom edge, the top horizontal wire just cleared the washers on the top row of 1/4 inch diameter bolts and the panel opened. When debris surrounded the shelter most escapes were made this way, and it is sad that the identity of the designer who suggested this great improvement is not known. The expensive

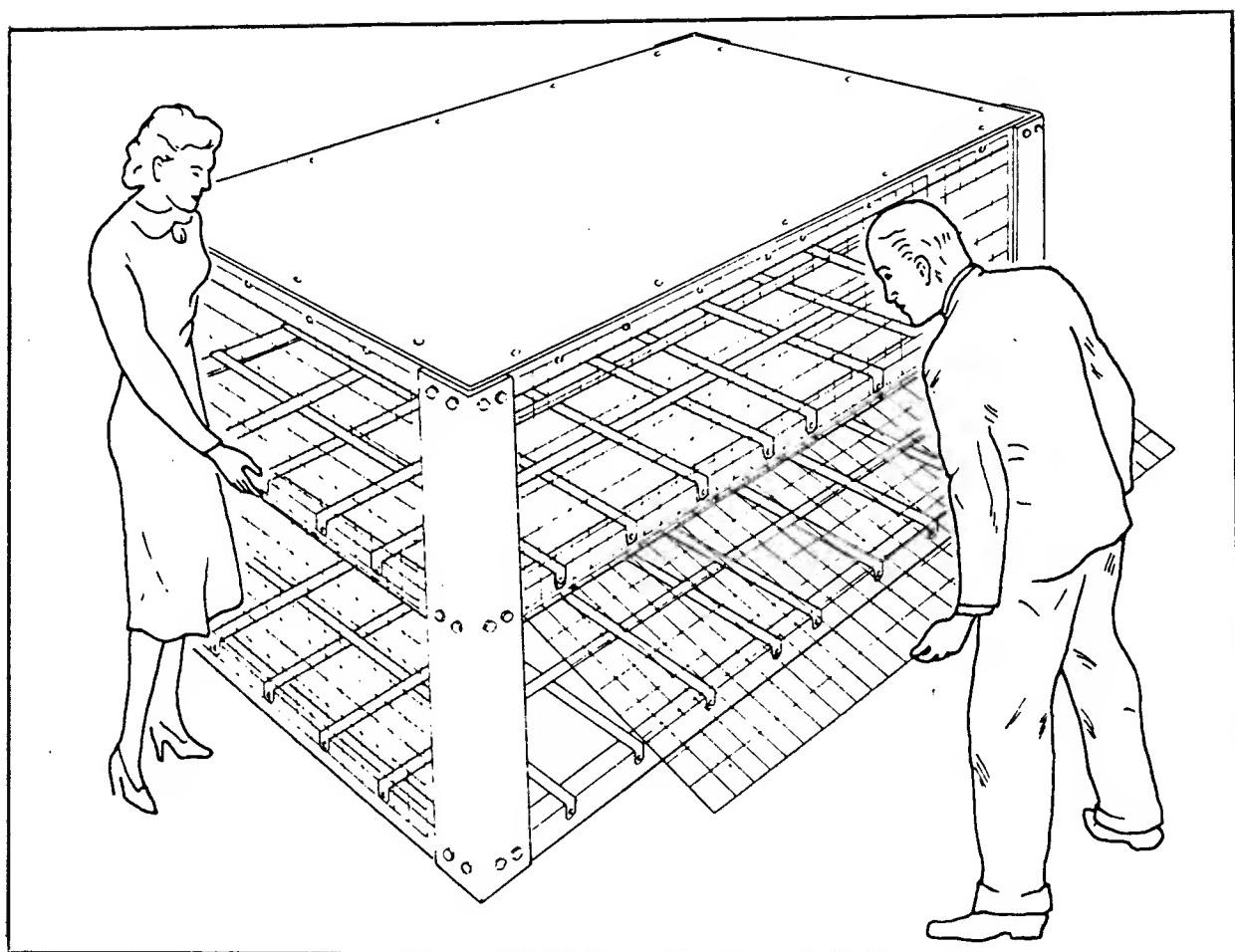


Morrison Shelter; Final Design

Fig. 3

turn-button arrangement of the prototype (Fig. 2) for keeping the panel hard up against the frame of the shelter was replaced by a cheap and simple wire hook and eye fastening joining the lower corners of adjacent panels inside the shelter as shown in Fig. 3.

The only item which remained to be redesigned was the mattress, for which weld-mesh was not available. This proved the most difficult problem and the only one which caused me real anxiety. The purpose of the mattress was not only to give the occupants some degree of comfort when lying quietly in the shelter but to contain them when the shelter was moved in an incident. The most severe test would come when the shelter was driven through the floor of the house and the mattress would be called upon to protect the occupants from the jagged broken floor boards. A promising suggestion was to return to the Victorian lath mattress which was formed by interlaced laths made of lengths of thin strip steel one inch wide. I liked this and produced a neat and economical way of securing the ends. These were bent through a right angle and held in place by the 1/4 inch diameter bolts provided, as described above, to secure the bottom of the side panel, as shown in the two tier shelter of Fig. 4. This produced a comfortable and immensely strong mattress. Unfortunately there was a sad snag, which well illustrates the complexity of engineering design problems. The steel strip had to be bent at the steel works, the distance between the bends being critical. Identical laths with bent ends would not "bundle" conveniently. That is to say they would not fit snugly together to form small neat bundles. I was informed by those responsible for transport that there were not enough railway trucks available to carry the awkward bundles of the many millions of bent laths required. This was hard to believe but the experts were adamant, and so the mattress was made of straight lath with a hole punched at each end through which wire attachments, a plain hook at one end and a hook and small spring at the other, were fixed, their other ends passing through holes in the horizontal leg of the bottom rails. This provided a satisfactory mattress for sleeping on but there was no way of making absolutely certain that it would behave perfectly when driven through a floor. The problem was not amenable to calculation and there was no time to carry out elaborate tests. However, unpalatable as it was, the decision had to be made. In fact, as was revealed later, though there were many incidents in which the mattress disintegrated when driven through a floor, the end wire hooks being pulled out of their holes, they hung on just long enough to protect the occupants and there was no evidence of injury from this cause.



Morrison Shelter: Final Design

Fig. 4

With the helpful cooperation of the members of Steel Control this work of redesigning was completed in less than a week. It resulted in a structure retaining all the principles embodied in that taken to Downing Street, except for slight reservations about the mattress, but differing radically in detail. It was a structure for which the materials were available to make half a million within the next three months and one simple enough for mass production without taxing the resources of the steel fabricating industry or straining the tax payer excessively, yet efficient enough to save the occupants of any house reduced to ruins by a near miss.

When this position had been reached, the Chief Engineer and others from Home Security came to Ashorne Hill where they met members of Steel Control around a table and in a few minutes the results of the hectic week's work were blessed and the necessary agreements initialled.

One other important step remained to be taken at Princes Risborough. From the discussions at Ashorne Hill it was clear that the target date of three months could not be met unless a multitude of small workshops, even those attached to village garages, were brought in as fabricators. Most of them were incapable of building a complete shelter, so the work was broken down and farmed out to those able to deal with individual parts. This meant that the parts had to be dimensioned so that, wherever they came from, they could be fitted together by unskilled labour, usually by Boy Scout volunteers. The structure was basically simple, but it was made of stout, intractable material; brute force would not help if the various holes through which a bolt had to fit did not register and if, when the main structure was erected, the side panels did not swing easily between their upper and lower fixings. This demanded careful calculation of what the engineer calls "tolerances," the definition of the limits within which the length of a member or the position of a hole must lie. This was put into the hands of Leader-Williams and this meant that the job was perfectly done so that there were no troubles in erection.

There was certainly no trouble over the dimensions of the parts but the production phase had only just got under way when reports came through of trouble experienced in the small workshops. The holes for the 3/4 inch diameter bolts were not drilled out of the structural steel angles. They were sheared out by a punch, a hard steel cylindrical tool provided by the Ministry, which was driven violently through the member so pushing out a small cylinder of steel, thus making the necessary hole. The trouble reported was that

the punches were fracturing. Inquiry showed that the steel of the angles was harder than the punches. Further inquiry revealed the awful fact that these structural members were not being rolled from normal structural steel but from an inferior material, known as "shell discard." This was that part of the steel ingot in which all the impurities collected, so that it was not suitable even for turning into shells. It was not good enough to fire from guns but it was good enough apparently to be made into shelters. It was, most certainly, not good enough. Shell discard steel was brittle and made a complete travesty of the indoor shelter. I was shocked. To issue an indoor table shelter designed on the principles of continuity and ductility, which was fabricated of brittle steel parts, was an act that did not bear contemplation. I made no enquiry of how it had happened or who was responsible. It may have been, on one side, an over-zealous steel salesman anxious to find a use for this unpopular steel or, on the other, someone supremely ignorant. Nothing useful would come of a witch hunt. All my energies were concentrated on correcting the error and, when the enormity of it was explained, everyone supported me so that, with the surprising speed that can be developed in war time, it was arranged that every consignment of steel for the shelters should be tested by independent engineers to ensure that it was ductile. After this, all went smoothly. In little more than the three months mentioned in Downing Street, the half million had been delivered and shortly afterwards were saving lives as will be described later.

However, this chapter must not be closed without another glance at the two-tier shelter of Fig. 4. It was issued in small numbers to households with very large families, but they did not call it into being. What happened was that in the early days of the issue of standard shelters an indignant letter was received accusing the Ministry of Home Security of encouraging immorality by issuing a double-bed for use by a household which might consist of a man and his house-keeper. The retort was an immediate order for the design of a two-tier shelter. This presented no problem and, since the number to be built was small, allowed the original lath mattress to be used, a matter of considerable satisfaction to me.

The shelter that has been described was known officially as the "Table (Morrison) Indoor Shelter" and popularly as the "Morrison." Donoughue and Jones, in their book Portrait of a Politician,⁵ attributed this, and the story carried by

⁵Bernard Donoughue and G. W. Jones, Herbert Morrison - Portrait of a Politician, Weidenfeld and Nicholson, London, 1973.

the press early in 1941 that Mr. Morrison himself invented the new shelter, to the inspiration of Clem Leslie, Morrison's faithful public relations officer. This may well have been so, but it seemed to us in RE4 quite natural that, just as the sectional shelter had been called after Anderson, the first Minister of Home Security, the new shelter should be called after the second. Morrison himself was in no doubt who was responsible for he wrote congratulating me in 1943, when I resigned from my post in his Ministry to take up new duties as Head of the Department of Engineering at Cambridge, saying generously, "If the shelter that has become associated with my name were the only result of your work the country would have had cause to be grateful to you." However, some years later he was not quite so certain. When towards the end of 1950 I was about to appear before the Royal Commission on Awards to Inventors, I felt that I would like to let Mr. Morrison know what was in the wind. By good fortune I saw that he was to address one of the University political clubs in Cambridge towards the end of the Michaelmas Term. After the meeting I went along to the University Arms Hotel, where he was staying, and found him sitting alone in the lounge. He soon remembered who I was but when I told him that I was about to make a bid for an award for the design of the indoor shelter, he nonplussed me by saying, "But I thought I designed it myself."

There is no doubt that hardware associated with his name for a long period leaves an impression on a politician. Years later when attending a dinner at the Dorchester Hotel, London, I found myself sitting next to Lord Waverley, formerly Sir John Anderson. I did not imagine that my name on the guest list would have conveyed anything to him, but during the soup course he turned to me and said:

"You had something to do with the Morrison shelter, didn't you?" I admitted that this was so. After a long pause, and not until the fish course, he said:

"It wasn't any good, was it?"

Though it seemed out of character, I thought he was pulling my leg gently so I said gaily:

"It was marvelous, the most successful structure ever to be designed."

"Nonsense," he replied irascibly, "it was useless. I should have opposed its adoption at the time, but I thought it politically inexpedient."

MORRISON INCIDENTS

The first recorded incidents, Cases 10a and 10b, Table 1, involving Morrison shelters were those of the 3rd/4th May 1941, that is, only four months after the prototype had been shown to Mr. Churchill. This reflects a remarkable achievement in the development and nationwide dispatch of a mass produced article; the result of team work that, to our discredit, only seems possible in war time. However, the first full report to reach the Research and Experiments Department was that of the incident, Case 16, which occurred at 2:30 in the morning of 14th June 1941 when a 50 kg bomb fell on a two-storey terrace house in Portsmouth. I look back to the reading of this report as one of my greatest thrills. It must be remembered that though the underlying principles were straightforward, they were new and the detail design had called for many decisions in an entirely unexplored field. Painful compromise had been faced, particularly in the design of the mattress, and there had been no long term testing program which would have been considered essential for any peace-time product before a mass production order covering half a million units had been undertaken.

The order having left our hands, we depended thereafter on the efficiency of our supply organisation. The millions of items had to be ordered from the steel industry and delivered to thousands of small workshops all over the country for fabrication. The 359 individual parts of each shelter had then to be collected together and delivered to the householder who, we hoped, would find the handbook we had written, How to put up your Morrison shelter, perfectly clear so that, with his Boy Scout helpers, he could produce the complete finished article exactly as we had designed it to be.

The success of a shelter is not only measured by the reduction in casualties. Quite as important is the comfort and peace of mind of the millions who used it every night and, on occasion, during the day time. An interesting testimonial is given by Norman Longmate in his fascinating history of everyday life during the War⁶ when he says: ". . . the Morrison proved the most successful shelter of the war, particularly during the 'hit and run' and flying-bomb raids when a family had only a few seconds to get under cover. It was also a good deal easier to erect than an Anderson, and while most people remember their nights in the Anderson with horror, memories of the Morrison shelter are usually good-humoured."

⁶Norman Longmate, How We Lived Then, Hutchinson and Co. Ltd., London, 1971.

TABLE 1

Fate of occupants of Morrison shelters in houses badly damaged by near-misses or direct hits from small bombs.

| Case No. | Number of occupants in shelter | Casualties | | |
|--|-----------------------------------|------------|----------------------|--------------------|
| | | Killed | Seriously injured | Lightly injured |
| <i>Section A</i> | | | | |
| Houses completely demolished | 10(a) | 3 | 0 | 2 |
| | 10(b) | 3 + dog | 0 | 0 |
| | 16 | 1 + dog | 0 | 0 |
| | 17 | 4 | 0 | 0 |
| | 24 | 2 | 0 | 0 |
| | 28 | 4 | 0 | 0 |
| | 30 | 2 | 0 | 0 |
| | 31 | 2 | 0 | 0 |
| | 32 | 5 | 0 | 0 |
| | 35 | 2 | 0 | 0 |
| | 38 | 2 | 0 | 0 |
| | 39 | 4 | 0 | 0 |
| | 40 | 3 | 0 | 0 |
| | 41 | 5 | 0 | 0 |
| | 42 | 3 | 0 | 0 |
| | 43 | 4 | 0 | 0 |
| | 44 | 3 | 2 | 1 |
| | 45 | 1 | 0 | 0 |
| | 46 | 3 | 0 | 0 |
| | 47 | 5 | 1 | 4 |
| | 48 | 1 | 0 | 0 |
| | 50 | 6 | 0 | 0 |
| | 51 | 2 | 0 | 0 |
| | 52 | 5 | 0 | 2 |
| | 53 | 5 | 0 | 0 |
| | 54 | 6 | 0 | 0 |
| | 56 | 4 | 0 | 0 |
| | 57 | 4 | 0 | 1 |
| | 58 | 1 | 0 | 1 |
| | 59 | 1 | 0 | 0 |
| | 60 | 3 | 0 | 0 |
| | 62 | 4 | 0 | 0 |
| | 71(b) | 3 | 0 | 0 |
| | 71(c) | 2 | 0 | 1 |
| | 72 | 4 | 0 | 0 |
| | 73(b) | 3 | 0 | 0 |
| | 73(c) | 3 | 0 | 0 |
| | 77 | 1 | 0 | 0 |
| <i>Section B</i> | | | | |
| Houses damaged beyond repair | 33 | 4 | 0 | 1 |
| | 36 | 2 | 0 | 0 |
| | 63 | 5 | 0 | 0 |
| | 80 | 1 | 0 | 0 |
| <i>Section C</i> | | | | |
| Houses damaged so as to be uninhabitable | 13 | 2 | 0 | 0 |
| | 23 | 3 | 0 | 0 |
| Total | 136 | | 3 | 13 |
| | | | | 16 |

(A full discussion of the more important incidents included in this table will be found in Chapter 7 of Lord Baker's book)

Suggested questions and problems
for ECL 245 Enterprise versus Bureaucracy.

Design. Convert the "Report to the Lord Privy Seal" (page 6) to a brief design specification.

Compare the first and the final design. List all differences and the reasons for them.

Sketch several other methods for attaching straight lath to the horizontal bottom rail (page 23).

Tolerancing. Determine tolerances for the size and position of the holes by which legs and rails are fastened together. Make a toleranced drawing. (Fig. 3)
Show that your choice of tolerances is near optimum.

Same as above for the holes by which the top plate and the upper rails are fastened together. (This is easier than the first tolerancing problem).

Strength of Materials. The text mentions 3/4 inch bolts for joining legs to horizontal rails. Fig. 3 shows 3/8 inch bolts. Determine which of the two sizes provides a better balanced design. Determine the optimum bolt size, assuming that bolts are available in 1/16 inch diameter increments. (3/8 7/16 etc.)

Determine the energy required to produce incipient yielding (elastic limit) of the structure by applying a vertical force at the center of a long horizontal rail. State the maximum force, the maximum deflection and the energy. State your assumptions about joint fixity.

Determine the maximum force and the energy required to produce 8 inches deflection at the center of a long horizontal rail by applying a vertical force to it. Sketch the rail and show the areas where the material has yielded and is permanently stretched or upset.

Communication. Make a table of contents and outline for the instructions for assembling the shelter from the 359 component parts (page 28). Make some of the necessary sketches. Write the section on assembling the basic frame from the angle irons and illustrate it.

HOF
1979